Assessment of Rut-Resistance of Unbound Granular Bases

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ABSTRACT: Over the last decade a considerable amount of research effort has been focussed on the development of a repeated load triaxial (RLT) test procedure to assist practitioners in the use of natural and marginal unbound base/subbase materials in road pavements. A significant hindrance to the widespread adoption of the RLT test has been the lack of data linking the results of the laboratory test to field performance. In order to address this issue, a major Australian research project was undertaken to compare the deformation of four granular bases under accelerated loading with various laboratory performance tests, including wheel tracking and RLT. This report details the findings in terms of the usefulness of various laboratory tests to rank the deformation of granular bases under thin bituminous surfacings. The RLT test results have brought into question the usefulness of the axial permanent strains measured in the Austroads test method as these strains did not identify one of the four test materials as being unsuitable for base course due to its low resistance to lateral shoving. By contrast a wheel tracking test, similar to that widely used for asphalt rut-resistance correlated reasonably well with the accelerated loading results.

KEY WORDS: Unbound, granular, rutting, repeated load triaxial, wheel tracking.

1 INTRODUCTION

Australasia has led the world for many years in the design and management of sealed unbound granular pavements. This has allowed sealed road access to areas which otherwise would only be serviced by gravel roads, as well as reducing the total cost of construction and maintenance across the network. However, road authorities in Australia and New Zealand are coming under increasing pressure to deliver higher levels of serviceability to the road user, in a climate of continuing changes in traffic loadings (increasing traffic volumes, high axle loads and new generation vehicles), scarcity of resources (reduction in high quality traditional materials and increasing use of alternative materials such as recycled materials and industrial wastes) and moisture/thermal environments (increasing consumption of water for irrigation, changes in landscape and climatic and thermal changes.

Currently, most design, material specification and construction technologies for sprayed sealed surfaced unbound granular pavements are still empirically based. One significant deficiency in the specification of granular materials is the lack of a reliable test to estimate the deformation of these materials in-service. There is a need to develop and/or refine the existing performance based specification (PBS) approach to the specification of unbound granular materials in Australia and New Zealand.

Austroads member authorities consider the repeated load triaxial (RLT) test to be the best candidate laboratory performance test to pursue new material performance measures (such as shear strength, resilient modulus and pavement layer deformation) for use in the PBS of granular materials and in a mechanistic pavement design procedure to predict the performance of granular pavement with thin bituminous surfaced seals in-service. However, its widespread use has been hindered by the lack of data relating the laboratory RLT test results to field performance and procedures for incorporation of laboratory RLT test results into performance-based specifications and mechanistic pavement design for unbound granular materials.

In order to address this issue, a major Australian research project was undertaken to compare the deformation of four granular bases under accelerated loading with various laboratory performance tests, including wheel tracking and RLT. This report details the findings in terms of the usefulness of various laboratory tests to rank the deformation of granular bases under thin bituminous surfacings.

3 MATERIALS SELECTION

With a view to evaluating which of the parameters from the RLT test best correlate with accelerated pavement tests and field performance, it was important that the materials used be carefully selected so as to cover a range of material qualities. Accordingly, twelve candidate base materials were nominated by Austroads member authorities. These materials were tested using both current empirical specification tests for material qualities (LA Abrasion, grading, Plasticity Index, etc.) and advanced laboratory test methods for mechanical properties including permanent strain and resilient modulus using the RLT test (Austroads 2007a).

Based on the past field performance, material specification results and laboratory RLT testing results documented in the report, Austroads (2007b) selected four base materials for accelerated pavement testing (Table 1).

The average particle size distributions of the bases prior to trafficking are plotted in Figure 1.

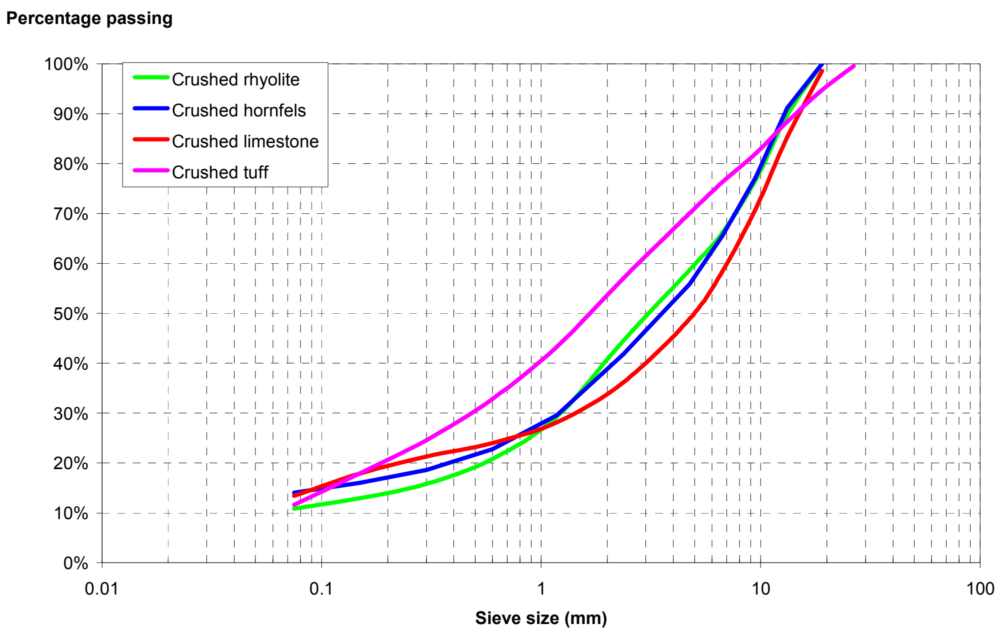
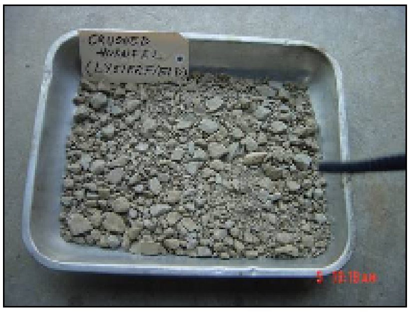


Figure 1: Average particle size distributions prior to trafficking.

Table 1: Selected base materials

Test material	Source rock	Comment[1]	
A	Crushed rhyolite	The Victorian crushed rhyolite is a typical good quality 20 mm crushed rock produced commercially at a quarry in the eastern Melbourne suburb of Montrose. It is an angular, rough, hard, blue-grey crushed rock containing some dolomite and some blue-grey sand silt. This material is hard crushed rock with LA of 12% but has added fines to improve its plasticity (PI of 4%). It meets VicRoads specification requirements for Class 1 crushed rock and has been widely used in Melbourne.	
B	Crushed hornfels	The Victorian crushed hornfels used in this study was obtained from a quarry in the south-eastern Melbourne suburb of Lysterfield. It has a fines content of 18% (exceeding the limit of 13% passing sieve 75 mm) and plasticity index of 9% and, therefore, is regarded as Class 3 material for subbase according to VicRoads specifications. Currently, this material is not used as crushed rock base material in Victoria.	
C	Crushed limestone	The crushed limestone was obtained from a quarry at Kulpara, near Port Wakefield in South Australia. The material has been used for granular overlay and several passing lanes on heavily trafficked roads (design life $>10^7$ ESA) during the last three years. This material is regarded as one of the better Class 1 materials available in South Australia.	
D	Crushed tuff	The Victorian crushed tuff was obtained from a quarry near Warrnambool in the south-western region of Victoria. Generally, tuff was made from what was originally volcanic ash. This ash was eventually buried to depths sufficient to produce temperatures and pressures necessary to petrify it into the tuff. Some tuff was later uplifted, and exposed to a secondary process. This extra process brings another mineral (mordenite) into the picture which acted much like glue and made this rock not only the colour it is, but also gave it added strength. This material is soft (LA = 45) and is high in fines. It is currently only used as base on lightly trafficked roads in south-western Victoria.	

Notes:

1. Comments are composites of extracts from Austroads (2007b).

4. PERFORMANCE UNDER ACCELERATED LOADING

4.1 Accelerated Loading Facility

The Accelerated Loading Facility (ALF) is a full scale pavement test system developed by the RTA NSW to enable assessment of road pavement performance within a short time scale. The ALF is owned and operated by ARRB Group.

For the tests described in this report, the ALF was housed at the ARRB indoor test facility, which includes a shed 54 m in length and 18 m wide, at Dandenong, Victoria (Figure 2).

Most of the ALF testing of the four unbound granular bases was conducted with 60 kN dual wheel loading.

Figure 2: The Australian ALF operating indoors at Dandenong, Victoria

4.2 Test Sections

In order to ensure that the only mode of distress for the constructed pavements would be permanent deformation, and that this deformation would be restricted to the base material, and not occur in any subbase materials, a base course thickness of 350 mm was selected for all four materials. A cement treated crushed rock subbase was placed under the granular bases for the following reasons (Austroads 2008b):

- to ensure that the material underlying the granular base was deformation resistant, thus limiting the total pavement deformation to the overlying granular base
- to provide a stiff layer against which construction compaction equipment could compact the granular material, and thereby ensure uniform densities were achieved both with pavement depth and also longitudinally along the test pavements.

4.2 Permanent deformation results

Table 2 and Figure 3 summarises the number of cycles of loading to 10 mm mean deformation for experiment and sub-section. For some experiments the deformation observed at the completion of loading was generally lower than the 10 mm terminal deformation criterion. In such cases, the cycles to 10 mm deformation needed to be extrapolated.

Table 2: Estimated cycles of loading to 10 mm mean surface deformation

Material	Experiment	60 kN ALF kilocycles to 10 mm deformation	40 kN ALF kilocycles to 10 mm deformation
Crushed rhyolite	3401	1160*	
Crushed hornfels	3403 Ch 9 to 12 m	6.5	
	3403 Ch 12.5 to 19 m	3.0	
	3404	3.6	
	3405 Ch 34 to 39 m		3.9
	3405 Ch 39.5 to 44 m		8.7
Crushed limestone	3407, Ch 21.5 to 25.5 m	74	
	3407, Ch 26 to 31.5 m	>1000*	
Crushed tuff	3409 Ch 9 to 12 m		350
	3409 Ch 12.5 to 19 m		135
	3410	83	

* extrapolated

As seen from the data in Table 2 and Figure 3, the crushed hornfels rutted rapidly under 60 kN loading (Experiments 3403 and 3404). Accordingly it was decided to reduce the applied load to 40 kN and retest in Experiment 3405. Notwithstanding, the reduced load, the hornfels again rutted rapidly.

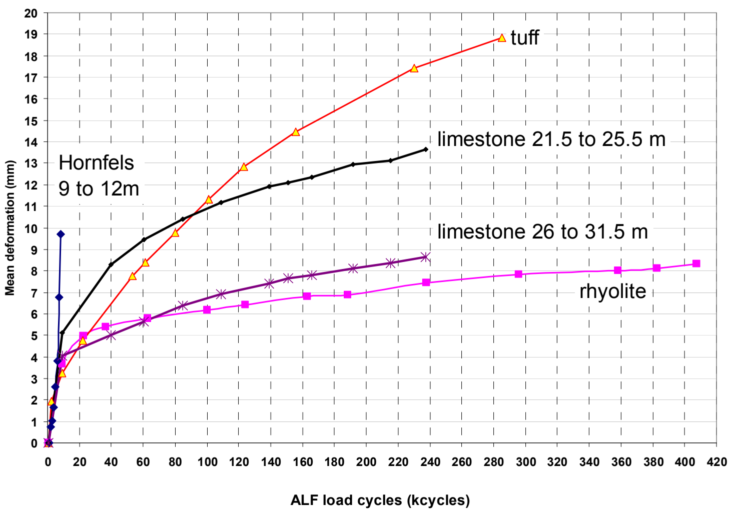


Figure 3: Summary of measured deformations under 60kN accelerated loading

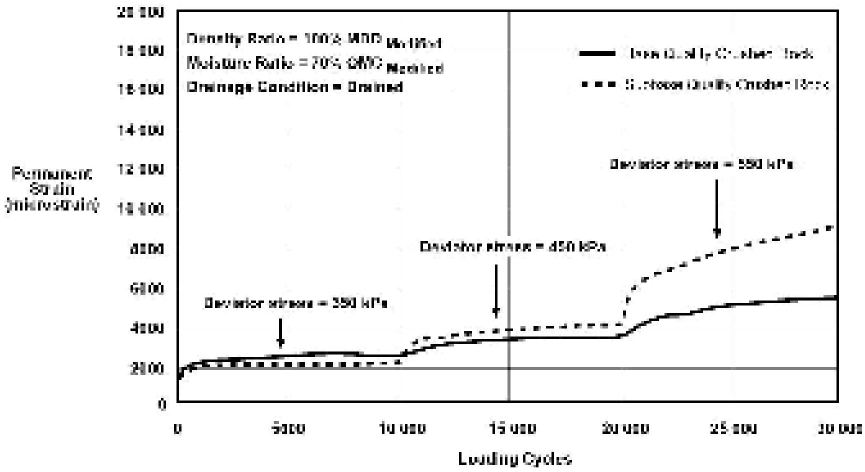
5. LABORATORY ASSESSMENT OF BASES

5.1 Repeated Load Triaxial Test

The Austroads (2007) permanent deformation testing procedure characterises the vertical permanent deformation at three stress conditions, viz. using three levels of dynamic deviator stress (σ1 – σ3) levels of 350, 450 and 550 kPa and a static lateral stress of 50 kPa, each stress condition consisting of 10,000 repetitions. Based on the test results, stress-dependent characteristics of permanent strain for the material can be determined. Multiple tests at different density and moisture conditions may be required to assess the sensitivity of moisture and density of the material.

Test materials are compacted in a split mould in five layers using a drop hammer to produce specimens 100 mm in diameter and 200 mm high. Materials up to a maximum particle size of 19 mm may be tested.

Figure 4 shows examples of relationships between permanent deformation and loading cycles for base and subbase quality crushed rocks. Several test values (e.g. deformation rate per 1000 cycles, and maximum deformation after each loading stage) are extracted from the test results for use in assessing the potential for permanent deformation in the field. The objective of this project was to assess which test values best correlate with performance under accelerated loading.



Source: Austroads (2008).

Figure 4: Example relationships between axial permanent strain and loading cycles

Table 3 summarises the measured permanent strains in each of three stress stages. Comparing the strains in Table 3 with the estimated cycles of loading to 10 mm field deformation (Table 2), it is apparent the strains in Stages 2 and 3 were poorly correlated with field performance. However, if the deformation in the first 50 cycles is not considered then again the Stage 1 deformations fail to reflect the vastly inferior performance of the hornfels to that of the rhyolite and limestone. It is only the initial 50 cycles of loading of the permanent strain test that ranks the bases in a manner consistent with their field performance. Unfortunately, the deformation in the first 50 cycles is highly variable, being influenced by the procedure used to finish the top of the test specimens. As such, the strain after the first 50 cycles is not a reliable performance index.

Table 3: Measured permanent axial strains at field densities and moistures

Material	Permanent axial strain in Stage 1 (microstrain)			Incremental permanent strain in Stage 2 (microstrain)	Incremental permanent strain in Stage 3 (microstrain)
	All cycles Stage 1	Strain after first 50 cycles	Stage 1 less strain after first 50 cycles		
Crushed rhyolite	5540	3050	2490	1060	2720
Crushed hornfels	10,280	7800	2480	780	2400
Crushed limestone	5670	3240	2430	1370	5300
Crushed tuff	8310	5060	3250	3270	>7000

It was observed that the ranking of the three materials other than the hornfels agreed with the accelerated loading results (Table 2). Hence, the principal deficiency of the test was its inability to identify the rapid rutting of the crushed hornfels due to inadequate resistance to lateral shoving.

5.2 Static Shear Test Results

The shear strength of the four bases was measured in accordance with the standard test (AS 1289-6.4.1, Standards Australia 2003. Generally, shear failure tests should be conducted on three to four specimens for each material (compacted to a single density-moisture condition) at different constant confining pressures (e.g. 25, 50, 75 and 100 kPa) to enable derivation of general failure relationships, which are used to calculate shear strength (failure stress) at a given applied confining stress. However, the test method allows three levels of failure stress to be applied to a single test specimen (compacted to a specified combination of density and moisture content) to reduce the testing effort.

Table 4 summarises Mohr-Coulomb criteria parameters and shear strength results for the four bases at the field densities and moisture contents.

Table 4: Specimens used in the shear strength triaxial testing program

Material	Dry density (t/m^3)	Moisture content (%)	Frictional angle (degree)	Cohesion (kPa)	Shear strength at mean stress of 200 kPa (kPa)	Shear strength at mean stress of 300 kPa (kPa)
Crushed rhyolite	2.28	3.0	60	70	590	820
Crushed hornfels	2.33	4.8	57	68	580	800
Crushed limestone	2.27	4.9	57	40	510	740
Crushed tuff	1.77	15.0	48	60	490	670

In principle, a material having a higher friction angle is more stable under a high confined stress condition; whereas a material having a higher cohesion value is more stable under a low confined stress condition. For the stress condition in the base layer, FEM pavement analysis (Vuong, 1999) indicated that the highest shear stress would occur at a depth of 75-100 mm, with typical mean stress of about 200 kPa and a difference between principal stresses (or deviator stress, $q = \sigma_1 - \sigma_3$) of 450 kPa. Therefore, to characterise the four bases the shear strengths were determined at the mean stress of 200 kPa and are given in Table 4.

It is seen from Table 4 that the measured static shear strengths of the rhyolite and hornfels are very similar at the field test densities and moistures. Again it seems that the laboratory test has not replicated the change in structure of the hornfels that occurred in the field under repeated loading.

5.3 Wheel Tracking Test Results

A possible reason the permanent strains measured Austroads laboratory RLT test did not closely correlate with rutting under accelerated loading is that this laboratory test does not include rotating shear stresses. Consequently it was of interest to assess whether a laboratory wheel tracker test would correlate more closely with the accelerated loading results.
The Roads and Traffic Authority New South Wales uses a wheel tracking device to test asphalt using a procedure similar to the European Large Wheel Tracking Test (European Standard 2004).

The four bases were compacted at the field moistures and to the field densities with a segmental roller in a mould to 700 mm length, 500 mm width and 300 mm depth. To inhibit evaporation of moisture from the compacted bases, the top of the base was sealed by applying a coat of polyurethane. This seal was left to cure overnight.

Each base was then loaded with a single tyre (125/75R8) inflated to 700 kPa loaded to 10 kN. The tyre had an overall diameter of about 380 mm, a contact width of 90 mm, a contact length of 125 mm, resulting in an average tyre-pavement contact stress of 1060 kPa. The deformation of the top of the base was measured during the application of 10,000 cycles of loading.

Table 5: Wheel tracking test results

Material	Deformation in first 50 cycles (mm)	Maximum deformation depth after 10,000 cycles (mm)	Deformation rate (mm/log(kcycle)) between 50 and 10,000 cycles	Ranking from wheel tracker test	Ranking from RLT test	Ranking under accelerated loading
Crushed rhyolite	1.7	2.5	0.16	1	3	1
Crushed hornfels	3.4	11.8	2.80	4	1	4
Crushed limestone	1.9	4.8	0.52	2	2	2
Crushed tuff	4.8	10.9	1.23	3	3	3

It is apparent from Figure 5 and Table 5 that the wheel tracking test results are more closely aligned with the accelerated loading results than the results of RLT testing.

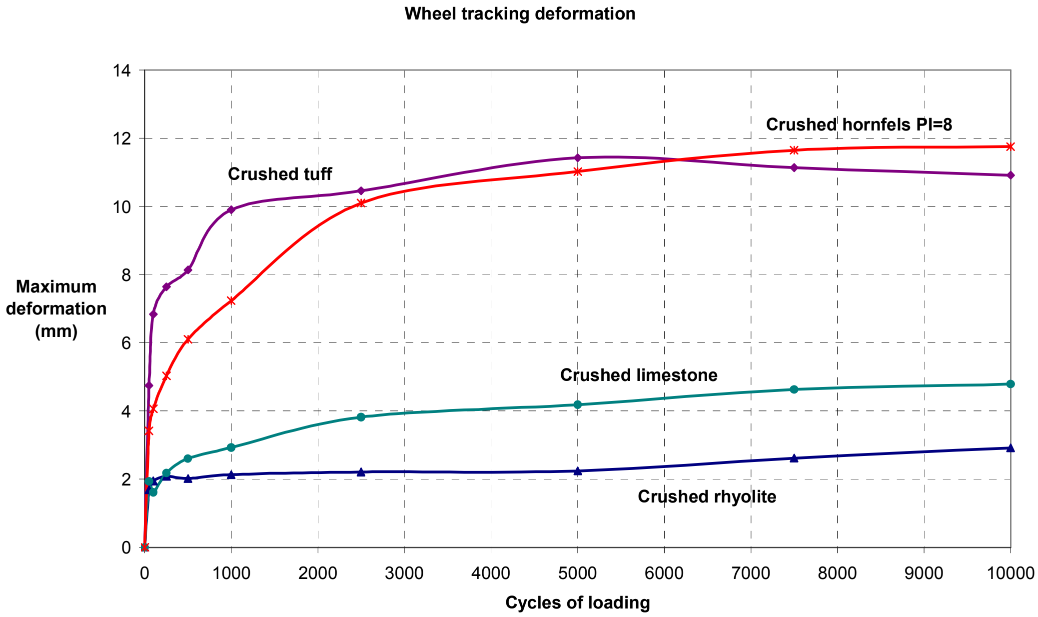


Figure 5: Wheel tracking results

6. CONCLUSIONS

Over 1 million cycles of accelerated loading were applied to the bases to assess their resistance to rutting. The observed ranking of materials in terms of rut resistance from best to worst was as follows:

- crushed rhyolite
- crushed limestone
- crushed tuff
- crushed hornfels with added plastic fines.

There was a marked difference in field performance with the crushed rhyolite deforming an average 8 mm after 400 kilocycles of 60 kN loading whereas the crushed hornfels reached the same level of deformation after only 2–5 kilocycles.

The bases were tested for rut resistance in a RLT test using constant confining pressure by ARRB Group using the Austroads test method. An unexpected result was that there was no indication from any of the existing processes to interpret laboratory permanent axial strain data that the crushed hornfels would fail rapidly under accelerated loading. In fact the permanent axial strains measured in Stages 2 and 3 of the test suggested the hornfels would be the best performer, which is of concern given its inferior field performance.

These findings have brought into question the usefulness of the permanent strains measured in the Austroads test method to characterise the rut resistance of granular bases under thin bituminous surfacings. The RLT permanent strain results did not identify the hornfels as a material unsuitable for base course due to its low resistance to lateral shoving. After less than 10,000 cycles of accelerated loading the hornfels changed in structure and reduced to a low stiffness material. The RLT test was not able to replicate this change to the granular structure.

The inability of the permanent strain test to identify the poor performance of the hornfels lends support to the contention that incorporating the aggregate interlock characteristics under the shear stress reversals that occur under rolling wheel loads is an integral part of a performance test for granular bases. It was concluded that the Austroads RLT permanent strain test is not suitable for characterising the resistance of granular bases to lateral shoving under thin bituminous surfacings. This is an important deficiency that significantly influences the usefulness of the test as a means of characterising rut resistance. This is not to suggest that the RLT test is not suitable to assess the deformation of granular materials and subbase under thick asphalt layers where the shear stresses are lower and densification rather than shear governs the rutting.

The wheel tracking results of the four granular bases correlated reasonably well with the accelerated loading results. It was concluded that the wheel tracking test is the most suitable test for the characterisation of the deformation of unbound bases under thin bituminous surfacings. This is not unexpected as the wheel tracking test is commonly used to assess asphalt rut resistance and the limitations of RLT in characterising asphalt shoving resistance has been recognised.

Consequently a new test is being developed for granular base rut resistance based on wheel tracking test.

7. REFERENECES

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